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Off-the-Shelf Technology for Gun Barrel Straightness Measurement, 10th U.S. Army Gun Dynamics Symposium

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Abstract

Gun barrel straightness is one of several manufacturing variables that must be held to a specified tolerance; therefore, barrel centerline measurement is a necessity. In the past, centerline measurement techniques have been developed specifically for this application, and machines to accomplish this have been produced on a small-quantity basis. This report describes the application of an off-the-shelf, three-dimensional laser tracker system, manufactured by Spatial Metrix Corporation (SMX), to measure the bore centerline of a 120-mm tank gun barrel. An introduction and tutorial about barrel straightness terminology, coordinate systems, and the level of precision required for such measurements are presented. A side-by-side comparison is then made between the SMX-based measurement and the standard or conventional measurement of several barrel centerlines, with the advantages and disadvantages of each system noted.

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1. Introduction

It has long been asserted that gun barrel centerline shape substantially affects gun accuracy. Projectile developers are quick to request and select tubes that exhibit smooth centerlines to ensure the least amount of in-bore disturbance possible. Tank trainees also desire near-the-norm centerlines since their qualification tests (tank table tests) could be jeopardized by atypical tubes. Thus, the ability to acquire and access centerline data is important to researchers as well as to users.

2. Terminology and Methodology

We define barrel straightness by specifying the path of the barrel's symmetrical axis. We can determine this, for example, by measuring the location of a bore-centered target as it moves down the tube. It is common practice to reference the bore centerline to a line drawn through the center of the bore either at its end points (see Figure 1a) or at its support points (see Figure 1b). The latter definition (1b) is adopted here. Watervliet Arsenal (WVA), in New York, typically performs gun centerline measurements in accordance with Figure 1a. This method is chosen because a maximum bend of 2 mm over the entire length is described by a maximum radius (basically "y" from the line joining the breech and muzzle centers) calculation at any one point. Figure 1a shows only the "y" distance to the centerline since "x" deviation contributions are typically much smaller.

Barrel centerline measurements must account for gravity effects as well as crookedness of the bore. We separate these attributes by subtracting measurements of the tube at 12 o'clock and 6 o'clock orientations. The difference is the barrel centerline. The removal of the centerline deviations from a measurement reveals the gravity effects or "droop," as it is termed. Tube measurements are taken every 200 mm. A barrel acceptance criterion states that the tube centerline, excluding droop, must not vary by 0.5 mm over a 600-mm distance or by 2 mm over the entire length of the tube [1,2]. These criteria created the need for a coordinate system that is easily understood and descriptive. The result was simply to have a translating "x-y" (2-D) coordinate at each measurement location. Positive y is upward and positive x is to the right. A self-centering target is moved down the tube, and its displacement from a virtual perfect centerline is noted. Measurements are performed with the tube held in the same manner as in the tank. These zero points are located at 670 and 1850 mm from the rear face of the tube. Neither the Aberdeen Test Center (ATC) nor WVA measurements include the chamber area and are simply for the projectile travel length. The centerline plots, such as Figure 1, begin at 230 mm (near the muzzle) and end at 4630 mm (near the bore start). Unfortunately, ATC measurements are taken in reverse of WVA measurements, since ATC's measurements begin near bore start and end near the muzzle. ATC has adhered to making measurements in the same bore locations as WVA for easy barrel comparison, and the figures presented follow this convention. ATC protocol is to obtain three measurements and use an average. As noted, the straightness measurements are composed of x and y displacements as the measurement devices move down the tube. The selected figures that follow simply give "y" measurements, since the elevation plane is where the largest deviations are commonly measured.

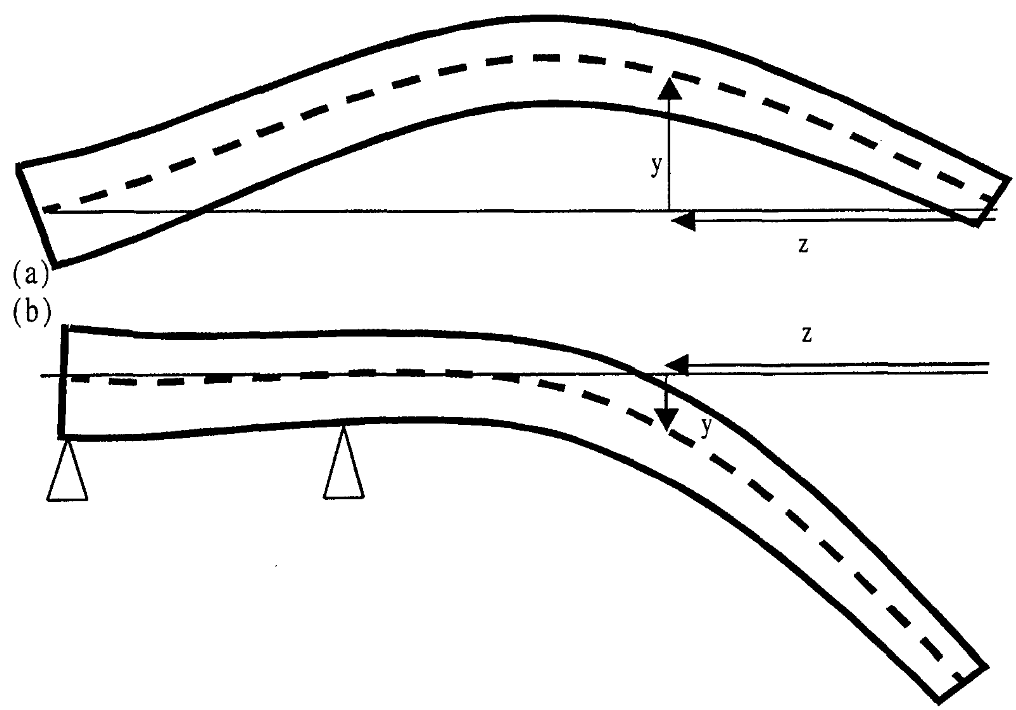

Figure 1. Two Methods of Specifying Barrel Curvature: (a) Relative to a Line Through the First and Last Bore Center Measurements, or (b) Relative to a Line Through the Bore Center at its Support Points.

3. Optical Centering Technique

An older method for estimating gun tube straightness is the optical method [3]. This method requires an alignment telescope and a backlit target on a bore-riding carrier. This method's accuracy largely depends on the skill of the operator. The optical method is time consuming, partially because of setup. The error involved is most easily reduced by the averaging of measurements. Figure 2 is derived from a set of optical measurements. The differences in the passes for the elevation graph are primarily caused by differences in resolution of the target motion. The differences between the graphs are on the order of 0.10 mm (0.004 in.).

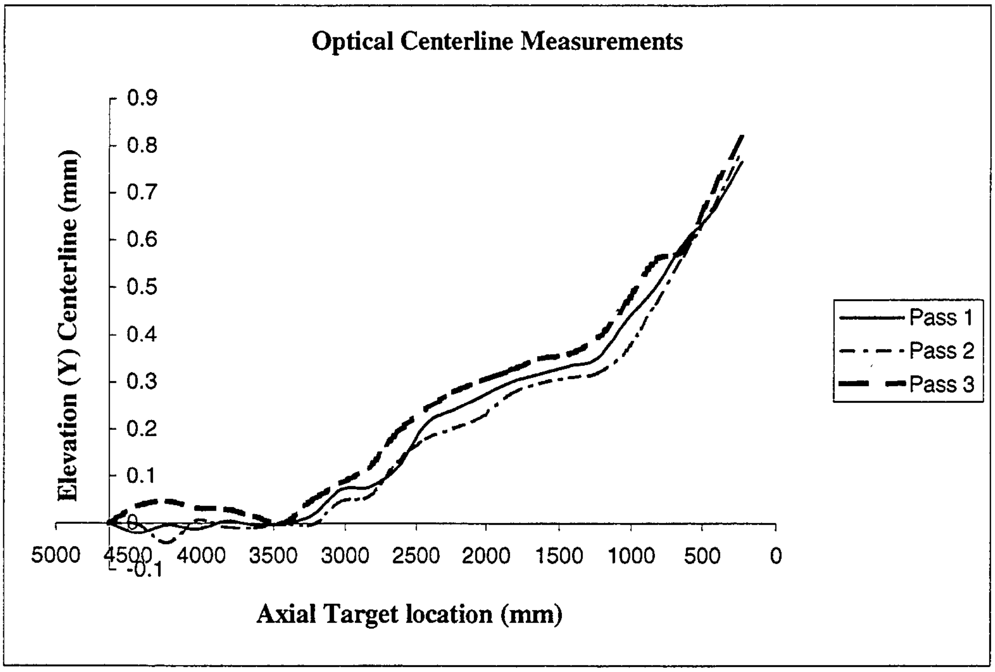

Figure 2. Typical Tube Centerline Elevation (Y) Deviations Via the Optical Method.

A step toward reducing the operator influences is offered in the gun tube inspection station (GTIS) method.

4. GTIS Measurement Technique

Straightness of the 120-mm tank gun tube is initially measured with a laser device, known as the GTIS (situated at the manufacturing plant in WVA) [4,5,6]. These measurements involve sensing the location of a laser spot on a target and the motion of the target relative to the reference laser beam as the target moves down the bore. The laser emitter fixture and the target are initially aligned (to establish a reference centerline) at the muzzle and bore start. The target resolution (where the laser beam strikes it) is governed by the number of pixels the target has and the spread of the beam. Ascertaining where the beam strikes the target requires the determination of the beam's center. While the laser beam is a focused source, its spread at a distance dictates that an averaging procedure be used to compute where the beam center actually is. This equipment generally produces consistent results. Unfortunately, the system requires "warm-up" over the course of 20 to 30 minutes. Measurements done before this warm-up period is finished show a bias not found in later readings. Concerns have also been expressed about inaccuracies that occur from rotation of the target head as it traverses the barrel. These are small but nonzero. Operator error is generally minimized over the optical method. One drawback of the GTIS equipment is that it has shown maintenance deficiencies. This situation forced ATC to use the optical method more frequently than the GTIS equipment. Figure 3 shows a set of GTIS measurements for an L55 barrel.

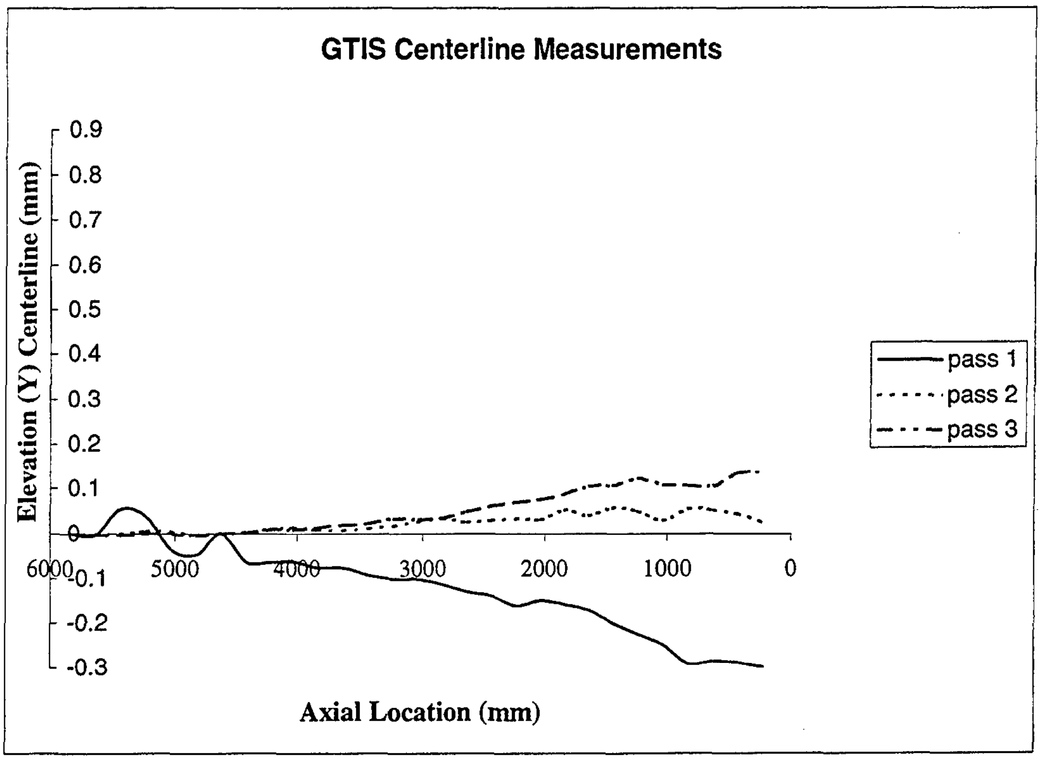

Figure 3. GTIS Centerline Elevation Measurements on an L55 Barrel.

5. SMX Measurement Technique

The Spatial Metrix (SMX) laser metrology system offers a host of improvements over the current gun tube measurement methods. A picture of the system is shown in Figure 4. The system uses a single tracking head that follows a spherically mounted reflector (SMR). This is opposed to laser-based triangulation methods that require the setup of two receiving heads. The setup for the SMX system requires environmental conditions of over 40° and below 110° F [7]. These restrictions are based on the ability of the equipment to modulate the laser beam so that it produces a constant wavelength of light. Operator checks are also required to assure that angular measurements and optical return power levels are satisfied.

Checks for point closure (the ability to re-measure a point and get the same value as obtained previously) are easily performed by operators returning to measured points and noting differences (if any) from previous measurements. Tolerance levels can be entered to warn of potentially inaccurate readings. These setups and verifications take approximately 20 to 30 minutes to perform. The SMX system uses interferometry measurements from the returned laser beam to determine the location of the SMR. The SMR is positioned in a fixture mounted to the same self-centering target apparatus used in the optical method discussed previously. We center the SMR on the target once by centering a "nest," in which the SMR rests. During measurement, the SMR is moved to the preset axial locations used under the GTIS and optical measurement practices, and measurements are taken.

Because the receiving head of the SMX system tracks the SMR's motion, it continuously measures location at a 1-kHz rate. It records these data when instructed and then averages the most recent measurements to minimize the effect of spurious readings. Accuracies of approximately 0.0001 inch are realizable when centerlines are measured with the SMX system. This compares to a 0.001-inch accuracy with the optical method. Recording data with the SMX system simply requires a button push once the SMR is placed at the desired measurement points. The burden of having to optically judge the change in location of the target center is removed, and the operator's biggest concern is assuring that readings occur at the proper axial points. Making centerline measurements in this manner (once the system is set up) is a 5-minute process.

Other data acquisition techniques via the system may further reduce the measurement time to less than a minute. These techniques have not been pursued to date. A comparison with previous methods is more obvious when axial measurement points are identical, and this temporarily precludes the use of the advanced method. These more advanced techniques also require slightly more familiarization with the system. They will eventually be employed. The removal of the judgment of target motion has also tremendously increased the repeatability of the measurements. This makes the system equally effective to all users with reasonable skill. Perhaps the best feature of the new measurement technique is the removal of pencil and paper for recording measurements. The measurements are stored electronically and are readily transferable to graphics packages for review. Furthermore, the data are easily transferable via electronic means to interested parties. The elimination of computer data entry to facilitate dispersal is key to accelerating the process and eliminating human error. Perhaps the most daunting attribute of the system is the cost. This cost is easily offset in the amount of time saved in measurement, data transmission and manipulation. New system costs are always a changing attribute since they typically drop over time as the technology becomes more accepted. The choice of accessories also impacts the cost of the system.

Figure 4. The SMX Tracker 4500 Metrology System.

While other tasks are not discussed here, the system has many other uses. Its portability and ease of use make it ideal for accurate test instrument location surveys, fragment dispersal, damage measurements, and rapid contour and part characterizations as well. These uses also potentially offset the high cost.

Figure 5 offers the same graph shown in Figure 2, with the SMX data set superimposed for easy comparison to previous data set. The SMX data fall within the envelope of the optical measurement plots and are so repeatable that variations between passes are difficult to detect. The repeatability of the data is shown in Figure 6. Small differences can be detected, but these may arise from not matching axial location perfectly.

The difference detectable is perhaps 0.01 mm. Finally, the maintenance required for the SMX system is an annual cleaning and "tuning" of the optics and electronics. Spare parts (such as extra SMRs) are included (as desired) in the purchase package. SMRs generally become damaged since they are handled most frequently.

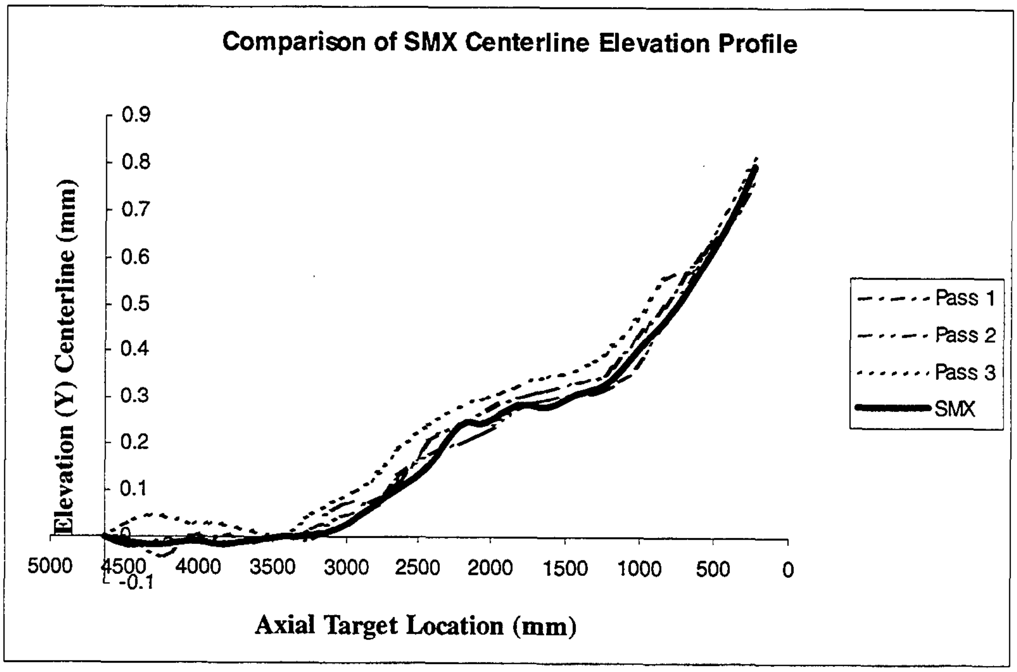

Figure 5. Comparison of Optical Measurement Technique to SMX Method.

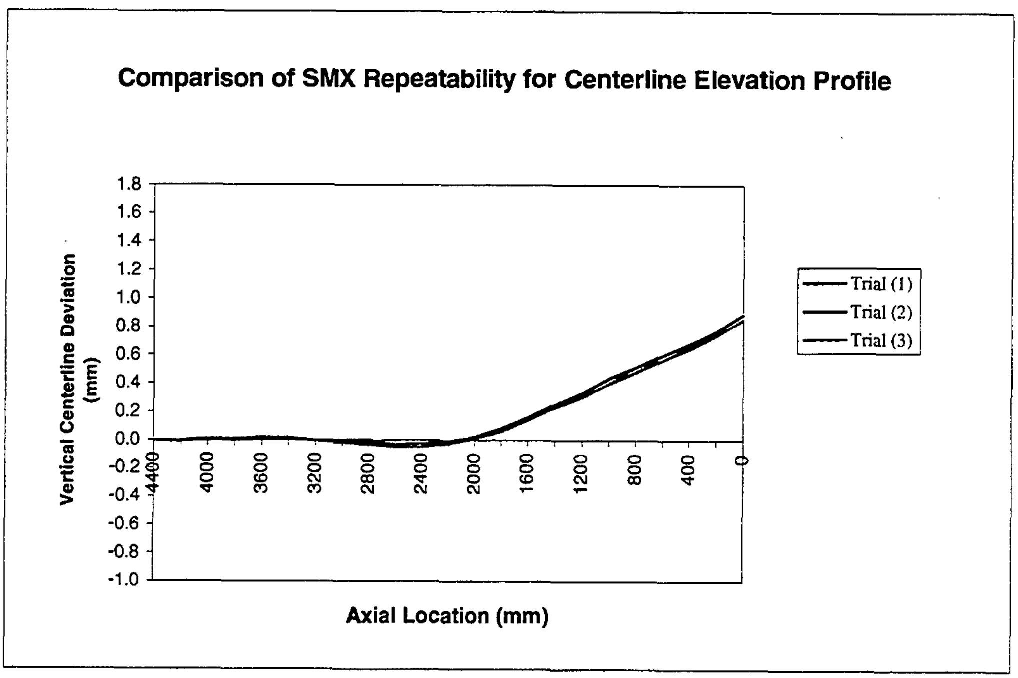

Figure 6. Comparison of Repeatability of SMX Method.

6. Conclusions

The SMX system is a significant advancement in the science of measuring gun tube centerlines. It conservatively allows bore measurement to proceed 10 times faster with a similar advance in data processing speed and distribution. The repeatability of the SMX system almost argues against doing more than one pass, although multiple passes are still performed to add an increased level of certainty to the data (multiple passes are also reasonable in light of the fact that each pass takes only 5 minutes). The SMX system's ease of use should expand the potential set of users as well. Enhancements to allow the measurement of tube diameter at axial locations with the SMX system are also in process. Despite the SMX system cost, it is a worthwhile step forward in the accurate measurement of gun attributes.

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